

# The Deconfinement Phase Transition in the Interior of Neutron Stars

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## Abstract

The deconfinement phase transition which happens in the interior of neutron stars are investigated. Coupled with the spin evolution of the stars, the effect of entropy production and deconfinement heat generation during the deconfinement phase transition in the mixed phase of the neutron stars are discussed. The entropy production of deconfinement phase transition can be act as a signature of phase transition, but less important and does not significantly change the thermal evolution of neutron stars. The deconfinement heat can change the thermal evolution of neutron star distinctly.

## 1 Introduction

The interior of neutron stars are considered as systems where high-density phase of strong interacting matter do exist. The chemical composition of neutron stars at densities beyond nuclear saturation densities ranging from purely nucleonic matter through hyperon or meson condensation to deconfined quark matter [1, 2]. Comparing with theoretical models with the observational data, we have opportunity to constrain or understanding fundamental elements of particle and nuclear physics. Many works believed that the appearance of quark matter is implied in the structure and evolution of neutron stars [3, 4, 5, 6, 7, 8, 9]. The consequences of different phase scenarios and spin evolution for the thermal evolution of neutron stars have been reviewed in comparison with existing soft x-ray observation of thermal radiation from neutron star surfaces. They both depend sensitively on and to some extent determine the chemical composition of the stars [10, 11, 12, 13].

As neutron stars spin down and contract, their structure and composition change with the increasing density, and the quark matter may appear. We will discuss how

the increasing density affect the spin and thermal evolution of neutron stars which contain quark matter in the core. As mentioned in the work [17], the increasing density and changing chemical composition further imply additional entropy production in bulk and the release of the latent heat as particles cross any phase boundaries present. They also thought that this kind of additional entropy production during deconfinement phase transition should affect the spin and thermal evolution of neutron stars.

In our former work, we discussed that the occurrence of first-order deconfinement phase transition is accompanied by the release of energy which originates from the binding energy. Therefore, we introduced the deconfinement phase transition which happened in the mixed phase of neutron star in this paper. The energy released during the deconfinement phase transition can be calculated with different equation significantly [10, 11, 12, 15, 16].

In Sect. 2 we will review the deconfinement phase transition which happens in the core of neutron stars, compare entropy production and deconfinement heat. Its application to the spin and thermal evolution of neutron stars also will be discussed. The conclusion will be given out in Sect. 3.

## 2 Deconfinement phase transition

As the star spins down, the centrifugal force decreases continuously, increasing its internal density. At this current, the nuclear matter continuously converts into quark matter in an exothermic reaction, i.e.  $n \rightarrow u + 2d$ ,  $p \rightarrow 2u + d$ ,  $s$  quarks immediately appear after weak decay. Quarks are accumulating in the interior of the neutron star with decreasing rotation frequency.

In the work of M. Stejner et al. [17], the authors introduced a possible connection between the spin down and thermal evolution of the neutron stars with a deconfinement phase transition which originates from the spin-down-powered entropy production might affect the thermal evolution of the stars. The signature of the appearance of a pure quark matter core is related to the change in radius, chemical composition, structure and under certain circumstances the additional entropy production both in bulk and in the form of latent heat. For a star of constant density and temperature with a baryon number of  $10^{56}$ . A reasonable approximation of the total additional entropy production can be written as [17]:

$$H_L \sim 10^{41} T_9^2 \left( \frac{\rho}{f m^{-3}} \right)^{-1/3} \left( \frac{B}{10^{14} G} \right)^2 \left( \frac{\Omega}{6000 \text{ rad s}^{-1}} \right)^4 \text{ erg s}^{-1} \quad (1)$$

where  $\rho$  is the baryon number density of the stars.

For neutron stars in which mixed phase exist, this results in the first-order deconfinement phase transition with varying pressure. The change of enthalpy over the

transition region immediately leads to the release of energy. The released energy during such phase transition can heating the neutron stars at old ages. The work of [14] give out the calculation of energy release per baryon during such phase transitions. The thermal evolution of neutron star with deconfinement heating also have been discussed in [12]. Since the mean energy release per converted baryon has been obtained, heating luminosity of deconfinement heating can be written as [14]

$$H_D = N\delta\dot{q} \sim -N\bar{q}\frac{2\Omega\dot{\Omega}}{\Omega_\lambda^2} \sim 10^{45}(\frac{\bar{q}}{0.1MeV})(\frac{B}{10^{14}G})^2(\frac{\Omega}{6000rads^{-1}})^4 ergs^{-1} \quad (2)$$

where  $\bar{q}$  is the mean energy release per converted baryon.

With the help of different observations, a fraction of observable pulsar's thermal radiations were detected in soft X-ray and UV bands. These pulsars are middle aged ( $10^3 - 10^6 yr$ ) with temperature about  $0.3 - 1MK$  [18]. When the compact star is older than  $10^6 yr$ , the photo cooling dominated neutrino emission and the stars cool down rapidly. The temperature of such stars is too low to be measured through the thermal radiation based on traditional thermal evolution theories. PSR J0437-4715 has been detected in UV/FUV with HST [19]. The shape of the inferred spectrum suggests thermal emission from the whole neutron star surface of a surprisingly high temperature of about  $10^5 K$ . A powerful energy source should be operating in a Gyr-old neutron star to keep its surface at such high temperature. The heating effects are expect to be significant for old compact stars. Here, we will compare the two different energy generation mechanism with the observational data of PSR J0437-4715.

For PSR J0437-4715 with  $P = 5.76ms$ ,  $\dot{P} = 5.73 \times 10^{-20}$ , heating luminosity of deconfinement heating  $H_D 10^{31} ergs^{-1}$ . This estimate under no consideration of effects of space-time curvature is slight higher than the inferred thermal X-ray luminosity  $L_x 10^{29} ergS^{-1}$  [10]. The entropy production can be estimated to be  $H_L 10^{27} \times T_9^2 ergs^{-1}$  which is determined by the temperature of stars.As mentioned in the work [17],the signature of deconfinement found here is below the present observational sensitivity and not of sufficient strength to set apart the thermal evolution curves with temperature versus time for neutron stars.

### 3 Discussion and conclusions

The deconfinement phase transition during the spin-down of neutron stars have been discussed in this paper.We estimated the energy generation rate of the two different mechanisms during deconfinement phase transition. The entropy release during deconfinement phase transition which analyzed in the work [17] have found do not dominate the general thermal evolution of neutron star but they do complement the standard picture. The signature of deconfinement found in this work is below the present observational sensitivity and not of sufficient strength to set apart the cooling curves with temperature versus time for hybrid stars.

The energy generated from first-order phase transitions which can act as a heating mechanism during the thermal evolution of neutron stars. It can affect the thermal evolution of compact star significantly at older age.

But the equation of state of superdense matter is still a mystery and the stars distance and ages are uncertain. Therefore, constraint on the chemical composition of compact stars purely through thermal radiation will be limited. Other observed phenomena, such as critical rotation and limited mass-radius relationship [20, 21, 22, ?, 23, 24] should be used for this goal. The combination of different evolution processes, such as spin and thermal evolution of the stars which is mentioned in [17], is a useful way to understand superdense matter in the compact star.

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## Discussion

**D. Boss (University of Emperor):** The result is not trustable, since we are transmitting troops using frequency of 0.31 Hz.

**Med:** Professor Boss has discussed the possibility of signal mixture, however we have EM shielding.